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Life cycle assessment of the Danish electricity distribution network

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Abstract
Purpose This article provides life cycle inventory data for electricity distribution networks and a life cycle assessment (LCA) of the Danish transmission and distribution networks. The aim of the study was to evaluate the potential importance of environmental impacts associated with distribution, in current and future electricity systems.
Methods The functional unit was delivery of 1 kWh of electricity in Denmark. The focus of the assessment was distribution of electricity, and the related impacts were compared to the generation and transmission of electricity, in order to evaluate the importance of electricity distribution in Denmark. The 2010 Danish electricity distribution network was modeled, including power lines (50, 10, 0.4 kV), transformers (50/10 and 10/0.4 kV), and relevant auxiliary infrastructure (e.g., cable ditches, poles, and substations). Two types of 50 kV power lines (underground and overhead) and 0.4 kV (copper and aluminum) were modeled.
Results and discussion Electricity transmission and distribution provided nonnegligible impacts, related mainly to power losses. Impacts from electricity distribution were larger than those from transmission because of higher losses and higher complexity and material consumption. Infrastructure provided important contributions to metal depletion and freshwater eutrophication (copper and aluminum for manufacturing of the cables and associated recycling being the most important). Underground 50-kV lines had larger impacts than overhead lines, and 0.4-kV aluminum lines had lower impacts than comparable copper lines.
Conclusions A new specific dataset for infrastructure in the distribution network was provided and used to evaluate the role of electricity distribution in Denmark. Both transmission and distribution provided nonnegligible impacts. It was argued that the impacts from electricity distribution are likely to increase in the future, owing to more renewables and decentralized electricity generation, and that impacts from infrastructure may become significant compared to electricity generation itself. It was recommended that impacts from electricity distribution and related infrastructure are included in relevant LCA studies. The data provided here make this possible.

Keywords Decentralized generation · Electricity distribution · Electricity system · Electricity transmission · Life cycle assessment · Power lines · Renewable energy

1 Introduction

Nowadays, the electricity sector is responsible for large environmental impacts; in 2009, electricity and heat production contributed 41 % of greenhouse gas (GHG) emissions worldwide (International Energy Agency 2010). The environmental impacts from electricity delivered to the end users are the result of two types of contributions: (1) impacts from electricity generation itself (including fuel provision, direct emissions, e.g., from the stack of a thermal power plant and capital goods related to plant installations), and (2) impacts from transmission and distribution of the generated electricity (including power losses and infrastructure for transmission and distribution networks). Environmental assessment of electricity generation, however, often fails to include both types of impacts, thereby leading potentially to incorrect results.

The environmental impacts related to electricity generation are usually the main focus of life cycle assessment (LCA)

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studies directed at the electricity sector (e.g., Gagnon et al. 2002; Turconi et al. 2013; Weisser 2007), while very few studies have investigated transmission and distribution of electricity. Only a single LCA study (Cigre 2004) was found that included both electricity generation and the transmission and distribution phases. This study, however, is now outdated (it represents 1997 conditions), focused mostly on the role of overhead transmission lines rather than on the overall impacts from transmission and distribution networks, and only included GHG emissions, not other impact categories (transmission and distribution were estimated at 2 and 8 % of the overall GHG emissions for electricity provision to end users in Denmark). Electricity losses were found to cause the majority of impacts in relation to both transmission and distribution. Harrison et al. (2010) performed an LCA on the British electricity transmission network, again, focusing only on GHG emissions: out of 11 g CO_2 eq/kWh only 0.4 g CO_2 eq/kWh were attributed to materials and construction and the remainder to energy losses. While other studies (Bumby et al. 2010; Jones and McManus 2010; Jorge et al. 2011a, b) have provided data for individual components—e.g., power lines and transformers—only the British study provided data for an entire transmission network. A similar study focusing on an entire distribution network has not been identified.

Jones and McManus (2010) compared different types and installations for 11 kV cables, and Bumby et al. (2010) estimated impacts from overhead and underground distribution of electricity in the USA. Both studies identified power losses as the main responsible for impacts. Underground lines were associated with larger environmental burdens, especially if the materials were not recovered after the use phase. Jorge et al. (2011a, b) performed an LCA on a range of components used in the Danish transmission network, concluding that power losses were the main source of impacts and that infrastructure provided nonnegligible impacts. In addition to peer-reviewed literature, some manufacturers have provided Environmental Product Declarations based on an LCA of their products (e.g., ABB 2000, 2003).

While contributions from capital goods in electricity generation are usually included in LCAs of electricity generation technologies, the contributions from transmission and distribution are generally not yet fully considered (e.g., Tonini and Astrup 2012; Georgakellos 2012). Although power losses in some cases have been included, contributions from infrastructure related to electricity distribution have not yet been quantified, and the real importance of these capital goods, for the overall environmental profile of energy systems, is therefore still uncertain. Up to this date, no studies could be found assessing the environmental impacts over the entire life cycle of electricity distribution networks (although, as mentioned, a few studies provided data on individual components). Proper inclusion of the environmental impacts from electricity distribution is needed to provide a full LCA of electricity systems, and evaluate society's choices regarding electricity provision, and is essential to properly assess the environmental consequences of potential changes in future electricity generation and distribution systems. So far, the basis for such assessments has not yet been available.

This study provides the necessary data to perform a full LCA of electricity generation, including the electricity distribution network. The current Danish electricity distribution network was used as case study. The specific objectives were (1) to provide a complete dataset for infrastructure included in electricity distribution networks, (2) to quantify the environmental impacts related to electricity distribution in Denmark, and (3) to identify the specific contributions from infrastructure and energy losses in the Danish distribution network. Further, impacts from electricity distribution in Denmark were compared with those related to electricity transmission.

2 Materials and methods

2.1 LCA methodology

The functional unit of the study was the delivery of 1 kWh of electricity in Denmark. Distribution of electricity was the focus of the assessment, and the related impacts were compared to the generation and transmission of electricity, to evaluate the relevance of distribution in the Danish electricity system.

A selection of impact categories from the ReCiPe methodology (Goedkoop et al. 2009) was used: climate change, human toxicity, freshwater eutrophication, photochemical oxidant formation, terrestrial acidification, terrestrial ecotoxicity, fossil depletion, and metal depletion. The LCA software platform GaBi 4.4 (PE International 2010) was used for the analysis.

2.2 The Danish electricity network

The Danish electricity transmission network is owned and operated by national Transmission System Operator (TSO) Energinet.dk. It includes AC lines (400 and 150–132 kV) and High-Voltage Direct Current (HVDC), both within the country and connected to neighboring countries. The components of the transmission network in Denmark are described in Energinet.dk (2010a, b). In 2010, transmission losses were 2.2 % (Energinet.dk 2011).

Several companies own and operate the distribution network, which can be categorized according to three voltage levels: 60–30, 20–6, and 0.4 kV (Energinet.dk 2010b). In 2010, distribution losses were 4 % (Energinet.dk 2011). The Danish Climate Energy and Building Ministry (2012) defines as transmission all components operating at 100 kV or above, while distribution components are those that operate at less than 100 kV.

2.3 Study scope and system boundary

A simplified version of the Danish electricity distribution network was modeled. The network was assumed to be comprised only of power lines (50, 10, 0.4 kV), transformers (50/10 and 10/0.4 kV) and respective auxiliary infrastructure (e.g., cable ditches, poles, and substations). Concerning other equipment, such as switchgears and circuit breakers, cutoff rules were used, according to the literature (Jorge et al. 2011b) and data availability (more details are provided in Section 3.3).

Existing data were used to model electricity generation and transmission, namely Ecoinvent (Ecoinvent 2010); (Jorge et al. 2011a, b; Jorge and Hertwich 2013). The Danish electricity mix (Ecoinvent 2010) was used as the source of electricity for the network, as well as for all other processes, e.g., manufacturing. The network was assumed to be manufactured and assembled using current technology, even if the lifetime of each component was up to 40 years.

3 Life cycle inventory

Data used for the modeling of power lines, transformer stations, and other equipment are described in the following sections.

3.1 Power lines

Three levels of voltage were modeled: 50 kV (assumed to be representative of the 60–30 kV lines), 10 kV (representative of 20–6 kV), and 0.4 kV. This approach is commonly used to describe the Danish distribution network (Danish Energy Regulatory Authority 2007). Data for the length of the lines and type—i.e., overhead (OH) and underground (UG)—were calculated after Energinet.dk (2010a, b) and were representative of the Danish distribution network in the year 2009. Technical characteristics of the cables (e.g., materials of conductor and insulation) were extrapolated after data collected by Dansk Energi (2011, personal communication) from four anonymous distribution companies, corresponding to 3,000 km of cables (2 % of the network). For 50 kV, 5,826 km of underground aluminum cables with cross-linked polyethylene (PEX) insulation and 3,050 km overhead aluminum cables with steel core; for 10 kV, 63,207 km of underground aluminum cables with PEX insulation; and for 0.4 kV, 88,158 km underground aluminum cables with PEX insulation and 8,255 km underground copper cables with PEX insulation. The composition of the selected types of power cables was calculated based on manufacturer data (NKT Cables 2010) and is shown in Table 1. Energy consumption during manufacturing was assumed to depend on the materials used and followed the suggestions by Bumby et al. (2010): aluminum and steel, 0.458 kWh_{el}/kg and 1.79 MJ_{heat}/kg; copper, 0.231 kWh_{el}/kg; and plastics, 0.156 kWh_{el}/kg.

Wooden poles were included in the modeling for overhead power lines, as well as materials used for the installation of underground cables (e.g., asphalt). Wood from Sweden was used (500 km by truck) and 14 poles/km, treated/preserved to ensure a 40-year lifetime (Bolin and Smith 2011). Heavy machinery consumed 1,000 l of diesel for the installation of 1 km of both underground and overhead cables (Energinet.dk 2011, personal communication). For the construction of ditches for underground lines, additional machinery work, equivalent to 400 l of diesel per km, was used (Energinet.dk 2011, personal communication).

The lifetime of the cables was assumed to be 40 years. In contrast to Harrison et al. (2010), but according to Jones and McManus (2010), underground cables were assumed to be removed at the end-of-life stage and disposed of following the principles of the waste hierarchy (European Union 2008): 90 % of metals (Al, Cu, steel) and asphalt were recycled and 10 % landfilled; 90 % of PEX and polyethylene (PE) were incinerated and 10 % landfilled; and 100 % of the wooden poles were incinerated. Disassembly of the cables was assumed to take place in Denmark, after a 200-km transport by truck.

3.2 Transformer substations

Two types of substations were modeled: primary substation (50/10 kV) and secondary substation (10/0.4 kV). In 2009, the Danish electricity system accounted for 867 primary substations, containing an average of 1.58 transformers, each transformer with a 14 MVA capacity, and 69,996 secondary substations, with one 335 kVA transformer each (Energinet.dk

Table 1 Inventory for cables (underground, overhead)

Component	Material	50 kV		10 kV	0.4 kV	
		UG Al	UG Cu	UG Al	UG Al	OH Al
Sheath	PE	474	298	394	222	–
Earth	Cu	481	347	265	0	–
Insulation	PEX	1,303	413	725	156	–
Conductor	Cu	–	2,410	–	–	–
	Al	974	–	714	981	531
Support cable	Steel	–	–	–	–	177
Other[a]	–	81	13	41	38	–
Total		3,313	3,482	2,139	1,397	708

Data based on NKT Cables (2010). All units in kg/km

UG underground, *OH* overhead

[a] "Other" include "paper", "insulating tape," and "catalyst and stabilizer", which accounted individually for less than 1 % of the mass of the cable and are neglected

2010a). For each type of substation, any equipment other than the transformer (e.g., switchgears, controllers, etc.) was neglected. Data for each transformer were calculated from Environmental Product Declarations of two transformers with the same voltage and a similar capacity (ABB 2000, 2003) and are reported in Table 2. Transformers were assumed to be produced in Poland (ABB Denmark 2012, personal communication and ABB Poland 2012) (800 km by truck), with energy consumption during manufacturing proportional to their capacity: 0.467 kWh_{el}/kVA and 0.553 MJ_{heat}/kVA (Jorge et al. 2011b).

Primary substations are typically pad-mounted: a reinforced concrete foundation provides support to the transformer and prevents oil from reaching the ground in case of leakage. For the primary substation, 82,000 kg concrete and 28,000 kg steel were used (Energinet.dk 2011 personal communication). A common installation for secondary substations is a "compact secondary substation" (ABB Denmark 2002), consisting of a 397-kg steel and a 1,515-kg concrete foundation.

The lifetime of the transformers was assumed to be 30 years (ABB 2000, 2003), and the waste similar hierarchy principles to the cables were followed for the end-of-life phase: metals (Al, Cu, steel) were 90 % recycled and 10 % landfilled; transformer oil and wood were 100 % incinerated; and 100 % of insulation (cardboard and pressboard), paint, porcelain, and silver (traces) were landfilled. It was assumed that disassembly took place in Denmark (including transport corresponding to 200 km by truck), while the substation buildings were reused or converted for other usage and not demolished (Energinet.dk 2011, personal communication). Therefore, no impact was associated with their disposal.

Table 2 Inventory for transformers (based on ABB 2000, 2003)

Material	50/10 kV	10/0.4 kV
Aluminum	94	–
Aluminum wire	–	114
Aluminum sheet	–	86
Construction steel	10,006	324
Copper	8,673	–
Electrical steel	10,411	533
Insulation	656	60
Paint	210	–
Porcelain	125	11
Silver	0.08	–
Transformer oil	10,206	340
Wood	517	–
Other[a]	85	9
Total	40,983	1,477

Values in kg/transformer unit

[a] No data are available for "other," which constitute less than 1 % of the mass of the transformer and are neglected

3.3 Other equipment

An electrical grid needs specific equipment to ensure safe and reliable operation, e.g., circuit breakers and switchgears. The number of circuit breakers and switchgears in the Danish distribution network was unknown, and given the size and use of energy compared to the other infrastructure (i.e., power lines and transformers), the amount of material was assumed to be negligible. Jorge et al. (2011b) performed an LCA on different transmission equipment and found that only emissions of SF_6 from circuit breakers and switchgears were relevant for global warming. In fact, SF_6 (GWP=22,800) is used as a dielectric material in circuit breakers when voltage is over 1 kV. Given that the distribution network contained 40 tons of SF_6 (Dansk Energi 2012, personal communication), and assuming 0.1 % yearly losses, similar to Jorge et al. (2011b), the annual emission from the distribution network was estimated at 40 kg/year. In comparison, 335 kg were emitted from the Danish transmission network in 2009 (Energinet.dk 2010a).

4 Results and discussion

In the following sections are reported results for (1) impacts related to individual components of the distribution network, excluding power losses and (2) impacts related to the entire Danish electricity distribution network, including the effects of power losses in the system. This sequential approach allows us to discuss the magnitude of impacts from individual infrastructure more transparently, evaluate various alternatives (e.g., overhead vs. underground lines), and compare values provided for similar infrastructure components in the transmission networks with the existing literature (e.g., Jorge et al. 2011a, b). These aspects are followed by a discussion of the relative importance of infrastructure and power losses in the distribution network and the potential implications for life cycle assessment of future, more distributed energy generation.

4.1 Distribution network components

Figure 1 shows the impacts for 1 km of a distribution line for the selected impact categories. Manufacturing of the cables was the most influential process for most impact categories, owing to provision of raw materials, mainly copper and aluminum. Similar results were found by Bumby et al. (2010) and Jones and McManus (2010). Construction of ditches for underground lines had significant impacts on four categories: production of concrete leads to impacts on climate change and photochemical oxidant formation, while asphalt (used in urban

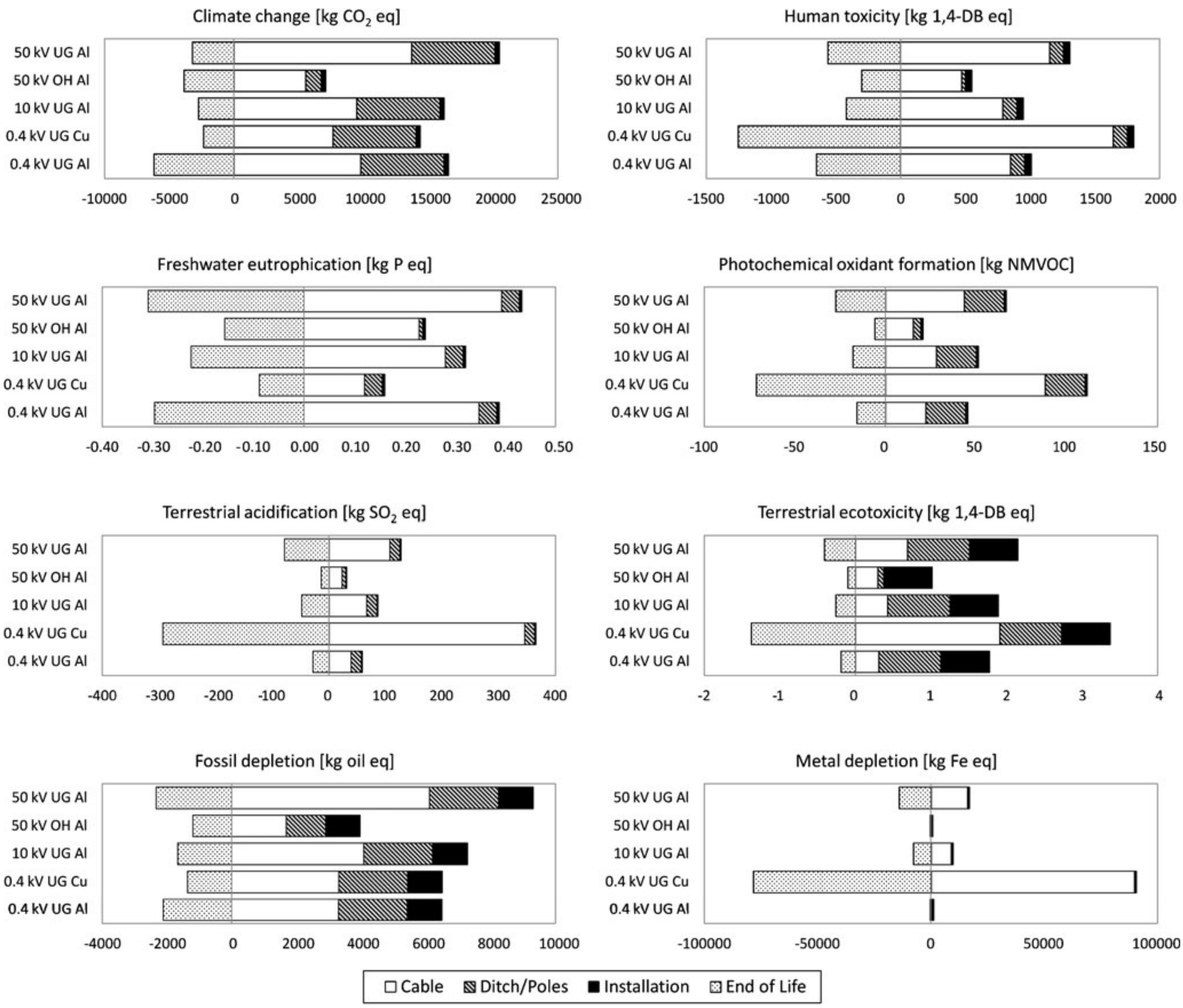

Fig. 1 Environmental impacts from 1 km power lines in the Danish electricity distribution network (*UG* underground, *OH* overhead)

installations) had impacts on terrestrial ecotoxicity and fossil depletion. Conversely, the manufacture of poles for overhead lines had significant impacts only for fossil depletion, owing to energy consumption during production of the wood preservation agent, as previously mentioned (Bolin and Smith 2011). "Installation," referring to machine work needed for laying the cables underground, or for mounting the cables on poles, mainly influenced terrestrial ecotoxicity and fossil depletion, from consumption of diesel for machinery. End-of-life processes provided savings to the environment for all impact categories, meaning that avoided impacts from the recovery of materials and energy were larger than the impacts caused by other end-of-life processes, e.g., landfill.

As the five power line types in Fig. 1 have different voltages, a direct comparison cannot be made. Two options, however, are available for 50 kV and for 0.4 kV. Overall, overhead 50 kV power lines had lower impacts for all impact categories compared to underground installations, confirming the findings of Bumby et al. (2010). This was mainly a result of the lower amount of aluminum and concrete required by overhead lines. Both 0.4 kV options referred to underground installations, but different conductor materials were used, copper and aluminum, respectively. Generally, the use of aluminum in power lines is increasing, owing to lower costs and lower power losses. For 0.4 kV lines in Fig. 1, aluminum generally offered lower environmental impacts than copper, in all impact categories except freshwater eutrophication. Owing to the high energy intensity of aluminum production, this was, however, only valid with high recycling rates.

Figure 2 shows the impacts for individual substation in the distribution network. Impacts from 50/10 kV substations were 10–40 times larger than those from 10/0.4 kV substations as a

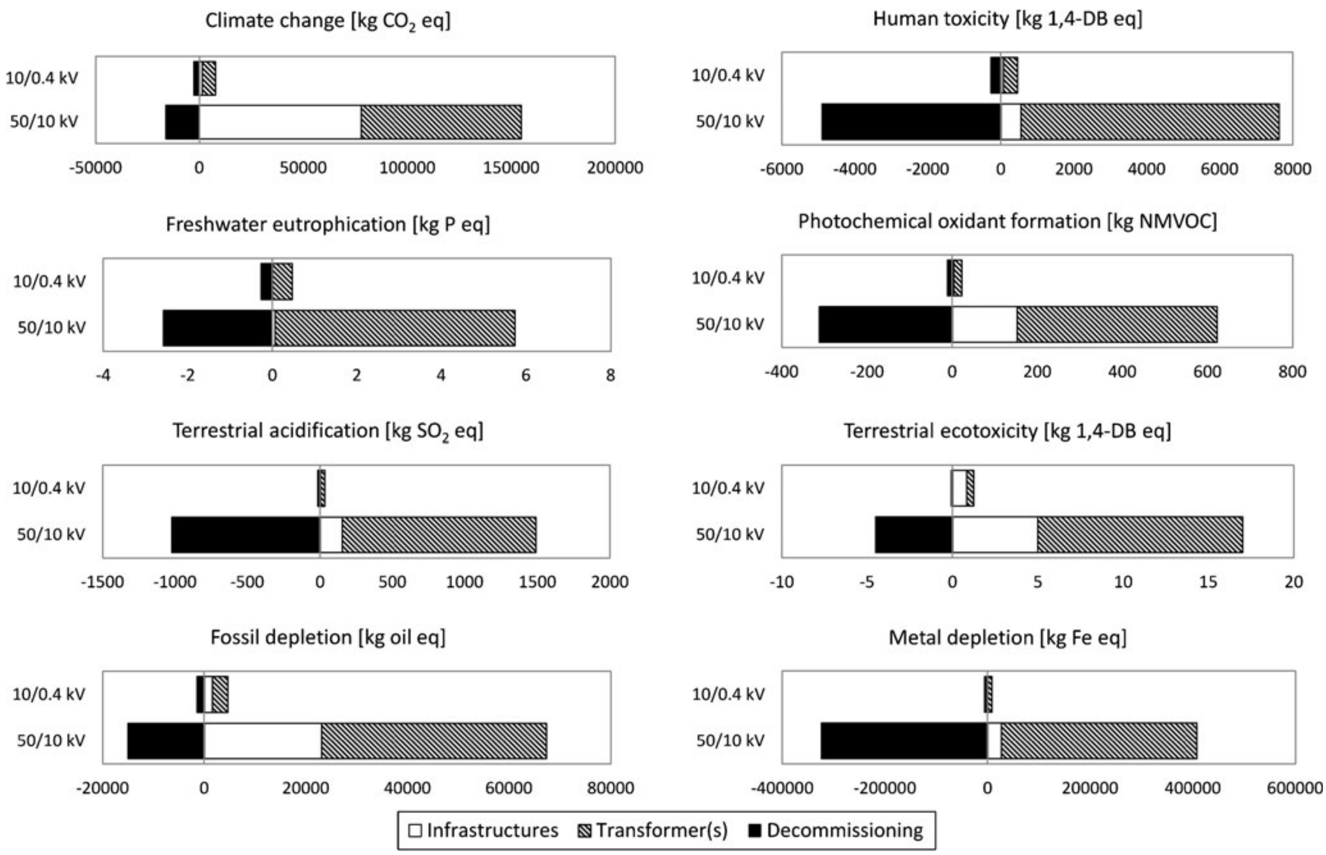

Fig. 2 Environmental impacts from transformer stations in the Danish electricity distribution network

result of the larger amounts of materials used, in particular, cement for the substation structure and steel and aluminum for the transformers. The structure of the substation contributed to the considerable impacts, up to more than 50 % of the total impact for climate change and terrestrial ecotoxicity, owing to the production of cement.

4.2 The Danish distribution network

When evaluated as part of the entire electricity system for delivering electricity to end users (generation, transmission, and distribution of electricity), the electricity distribution contributed with around 4–6 % of impacts in all categories, except metal depletion (11 %). The impacts from distribution were generally double to those related to transmission (2–3 %; metal depletion, 5 %). These values were consistent with data obtained by Cigre (2004), who reported 8 and 2 % for distribution and transmission, respectively, when considering that this study was based on data from mid-1990s, and distribution losses had decreased from about 6 % in 1995 (Energinet.dk 2010a) to 4 % in 2010 (Energinet.dk 2011).

Figure 3 shows the relative contributions from infrastructure and power losses in the Danish transmission and distribution networks. Impacts from distribution were 1.6–2.5 times larger than those from transmission, for all impact categories. Distribution had larger impacts compared to transmission for two reasons: (1) lower voltage causes higher losses and (2) distribution networks are more complex, leading to larger impacts from infrastructure (larger material consumption).

Power losses and infrastructure caused impacts of various magnitudes in the individual impact categories. Impacts related to climate change, terrestrial acidification, terrestrial ecotoxicity, photochemical oxidant formation, human toxicity, and fossil depletion were caused mainly by electricity generation. Therefore, losses constituted the main cause of impacts (89–94 % for distribution and 96–98 % for transmission). Similar results were found by Jorge et al. (2011a, b) and Harrison et al. (2010). Conversely, infrastructure had a greater influence on metal depletion, owing mostly to the use of aluminum, copper, and steel for cables and transformers. For this impact category, infrastructure was responsible for 68 % of the impacts within distribution and 51 % within transmission (power losses lead to metal depletion because of the extra generation capacity required for the electricity that is lost. In other words, a 5 % power loss in the distribution network is responsible for an oversizing of 5 % of the total capacity of power plants in Denmark). Freshwater eutrophication was caused mainly by power losses and energy consumption, in the production of aluminum and steel. Although power losses

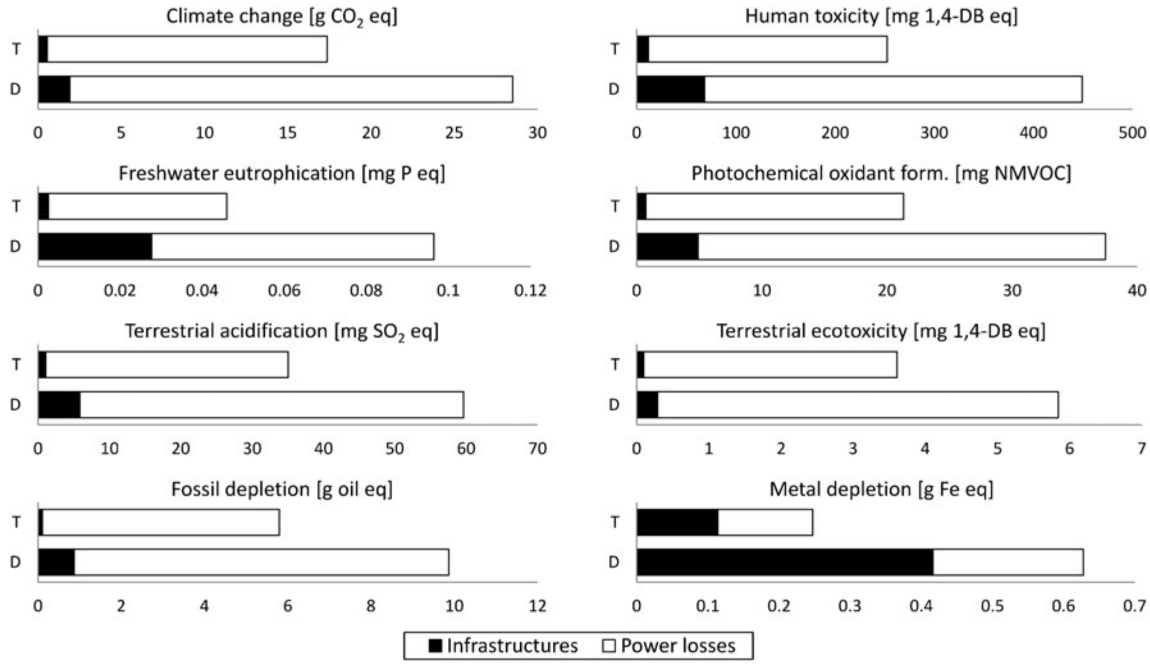

Fig. 3 Environmental impacts from transmission (*T*) and distribution (*D*) of 1 kWh of electricity in Denmark

in distribution were higher than in transmission, 12.5 mg of aluminum was used for distribution per kWh delivered compared with 0.5 mg for the transmission network. This resulted in 29 % of the freshwater eutrophication impacts being related to infrastructure in the distribution network but only 6 % in transmission.

Focusing on the infrastructure, Fig. 4 shows the relative contributions from the individual components of the transmission and distribution networks. For distribution, higher impacts were associated with the lower voltage lines. This was caused by higher material consumption required to carry the same electricity and the increasing complexity of the network for lower voltages (i.e., the total length of 0.4 kV lines was one order of magnitude larger than the 50 kV lines). The same pattern cannot be observed for transmission lines: 400 kV lines caused larger impacts than 150 kV because 400 kV also included long-distance interconnectors between Denmark and Norway, Sweden, and Germany, therefore having a larger capacity than 150 kV.

Within distribution, 10/0.4 kV substations and 0.4 kV aluminum lines caused the largest impacts for all categories because these network components were used most frequently, 69,996 units and 96,413 km, respectively. Substations of 10/0.4 kV accounted for 20–49 % of the total impacts from infrastructure depending on the impact category considered. For 0.4 kV power lines, the same value was 23–46 %. SF_6 leakage from switchgears and circuit breakers contributed to climate change, with 2 % of the total impacts for distribution and 41 % for transmission, owing to emissions of 40 and 335 kg SF_6/year, respectively. SF_6 emissions from distribution are negligible today. Nevertheless, the use of SF_6 is expected to increase in the future, with the implementation of smart grid

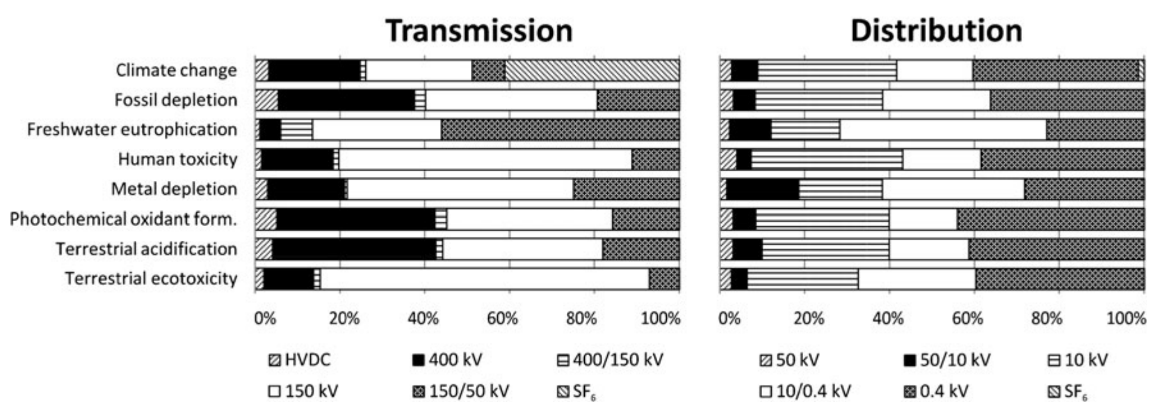

Fig. 4 Contributions to environmental impacts from infrastructure in the Danish transmission and distribution networks

technologies (Energinet.dk 2010b), thus we suggest including this emission in studies on future scenarios. The current policy of prioritizing material and energy recovery showed its beneficial effects, causing environmental savings.

4.3 Implications for assessment of electricity generation

Based on the results showed in Figs. 1, 2, 3, and 4, environmental impacts related to both transmission and distribution of electricity can be considered to be rather significant, even compared with generation. For example, Denmark generated 34 TWh of electricity in 2009 (48 % coal, 20 % wind, 19 % natural gas, 6 % biofuels, 5 % waste, and 3 % oil), resulting in the emission of 22 mio. ton CO_2 eq (Energinet.dk 2010a), including approximately 1 mio. ton CO_2 eq from distribution (i.e., 65,000 tons CO_2 eq from infrastructure and 910,000 tons CO_2 eq from power losses). Based on the results previously discussed, failing to include electricity distribution in LCA studies involving electricity generation or consumption may correspond to about 4–6 % of the overall impacts, depending on the impact category. While most impacts related to electricity distribution were associated with power losses, the infrastructure themselves contributed significantly to some impact categories (i.e., metal depletion and, to a minor extent, freshwater eutrophication). This highlights the importance of including impacts from both power losses and infrastructure, in order to avoid problem shifting.

Even for impact categories correlated strictly with power losses, such as climate change, infrastructure cannot be neglected as power losses and their impacts are likely to change in the future. The introduction of higher shares of renewables will, for many parameters, lower the direct impacts related to electricity generation, although upstream impacts—e.g., associated with provision of biomass—may increase (Tonini and Astrup 2012). Introduction of Smart Grids and more distributed electricity generation (causing the flow of electricity to change between transmission and distribution networks) will likely increase the load in the distribution network, thereby also inducing higher power losses for distribution (or requiring new infrastructure). While a cleaner electricity generation will lower the impacts related to power losses, the importance of impacts from infrastructure will increase and may become comparable to those associated with the electricity generation itself.

Typical ranges of CO_2 emission factors for electricity generation were estimated in Turconi et al. (2013) for different technologies such as nuclear (3–35 g CO_2 eq/kWh), hydro (2–20 g CO_2 eq/kWh), or wind power (3–41 g CO_2 eq/kWh). Comparing these emission factors with the impacts reported in the present study for infrastructure within distribution (2 g CO_2 eq/kWh), it can be seen that distribution related impacts are already within the same order of magnitude as the lowest end of the ranges reported for electricity generation. Climate change impacts from transmission and distribution could potentially affect the choice between, for example, nuclear power and photovoltaics. These two technologies have comparable GHG emissions related to electricity generation, 3–35 g CO_2 eq/kWh and 13–190 g CO_2 eq/kWh, respectively (Turconi et al. 2013), but the technologies feed in electricity at different voltage levels: nuclear at high voltage (making both transmission and distribution relevant), while small photovoltaic systems feed in electricity at lower voltages (making only part of the distribution network relevant). Therefore, a direct comparison between centralized and decentralized electricity generation systems cannot be made. Rather, impacts from transmission and distribution should be included in the LCA, according to their role in delivering the electricity to the end users. So far, this has not been done within LCA, and we recommend that these aspects are included in future studies.

5 Conclusions

Based on a detailed dataset for electricity distribution infrastructure in Denmark, the results clearly showed that distribution contributed with significantly larger impacts than those related to the transmission of electricity. Results regarding both single components and the entire distribution network are similar to those available in the literature. Thus, the infrastructure included in this study can be considered representative of countries with similar technological levels and geographical conditions and can be used as a basis for including distribution networks in LCA studies of energy systems elsewhere.

The impacts related to power losses in the Danish distribution network accounted for at least 90 % of the overall impacts from electricity distribution in most impact categories and were thus much larger than the impacts related to infrastructure. Metal depletion, however, was related mainly to infrastructure (66 %), owing to the use of copper and aluminum for cables and steel for transformers. The relative importance of power losses was higher for distribution than for transmission (94–98 % of impacts were related to power losses while 2–6 % to infrastructure).

Overall, environmental impacts from current electricity distribution can be considered nonneglectable when compared with the generation and transmission of electricity. With anticipated future developments of the electricity system towards more distributed electricity generation, and higher shares of renewables in the mix, it is concluded that the importance of environmental impacts from electricity distribution are likely to increase significantly. We recommend that this is reflected in future LCA studies involving electricity generation.

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